Modern Surveying Technology: availability and suitability for Heritage Building Surveying and Heritage Building Information Models (HerBIM)

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ABSTRACT: Surveying technology been used for the measurement and preservation of heritage buildings. With the recent advances in surveying much new technology is now available for extensive surveys of the built environment in general, and heritage buildings in particular. These technologies include laser scanning, digital terrestrial photogrammetry, Remote Sensing Satellites (Lidar), Unmanned Aerial Vehicles (UAV) ,Digital Aerial Photogrammetry, and Global Positioning Systems, in addition to Robotic total stations and other surveying technology.

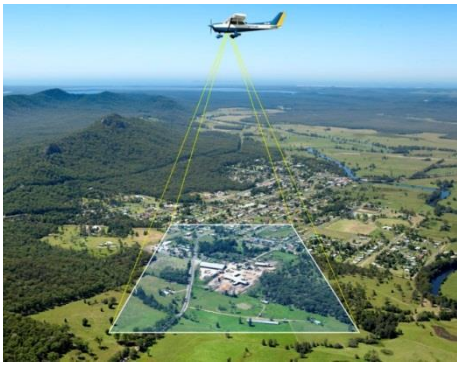
This paper reviews and evaluates the various modern surveying technologies availability and suitability, and their economy for Heritage building surveys, maintenance and preservation with particular reference to Laser Scanning and Building Information Models (BIM). Laser Scanning combined with digital terrestrial photogrammetry data also contains the passive colour (primary) of the material, as different surfaces reflect different laser light intensity (I).This yields a number of applications in addition to building surveys and building conservation.

BIM is the process of creating and managing building data from the conceptual design stages through to demolition. It is a digital three-dimensional, real-time, dynamic building management system which can increase productivity and improve quality throughout building design, construction, use, maintenance and demolition. The system inter-connects the spatial building data to all construction materials, processes, use and maintenance throughout its functional life to demolition, which can then be shared by all parties. In the UK the BIM project is well underway for government contracts £50 million and over. In particular the paper focuses on the use of surveying technology in the creation of Point Clouds and Digital Surface Models (DSM) and its integration into Heritage Buildings Information Models (HerBIM) for building maintenance, and preservation through digital documentation. Furthermore HerBIM should enable us to form Virtual Museums (HerVM) for national and international heritage sites for everyone to see, learn and enjoy.

1 INTRODUCTION

Traditional surveying techniques have been extensively used in the preparation and production of documentation in the form of maps, building plans, elevations, sections and various geometric representations. These techniques included traditional land surveying and aerial surveying, including remote sensing satellites and photogrammetry. Most of this information is now documented on paper and has recently been converted into digital scanned files. With the recent digital revolution and the availability of powerful information technology through enhanced computer power availability, surveying was in the forefront of advancing technology. The relatively new surveying technology such as terrestrial and aerial laser scanning, and digital photogrammetry (both terrestrial and aerial) supported by Global Positioning Systems opened up whole new horizons for both new and traditional applications. The importance of these technologies to heritage building and heritage preservation is clear. As an example, the Heritage 3D project by English Heritage (Heritage.com 3D,2011), the 3D project by Scottish Heritage and the worldwide campaign for the world heritage promote preservation through the application of these modern technologies .The aim of this paper is to introduce the built environment and Heritage professionals to these technologies, showing their availability, suitability, economy and accuracy, and how they may be used as a separate or integrated complementary technology, particularly for heritage building preservation and maintenance. Indeed, the availability of these technologies not only enables us to have full digital documentation of the heritage but also allows world wide access to our heritage.

2 PHOTOGRAMMETRY



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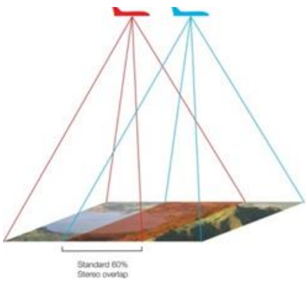
This is the science of precise measurements from photography. The photographs may be aerial, by using specially adapted aircraft and metric camera's, or terrestrially obtained on the ground surface. Low level aerial photographs are used for precise 3D measurements for many applications including topographic mapping, man-made and natural features, urban planning maps for cities and towns, engineering and construction, archaeology, heritage documentation and preservation. The principle of photogrammetric measurements depends on the reconstruction of the three dimensional view of the flown site. This is achieved by taking successive overlapping photographs both in the direction of the flight and sideways between strips. Traditionally stereo metric aerial cameras are used to produce stereo models of the site. Precise 3D data is measured from these models after photogrammetric restitution using stereoplotters. The density and the accuracy of this data(X, Y and Z) will depend on the flying height of the aerial photography, topography, features measured and the processing techniques. The cost of flying an area using survey aircraft is relatively high as compared to other available modern technology.



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Other alternative methods of flying an area are the use of Unmanned Aerial Vehicles (UAV's). Recently a number of UAV's have been developed and used for a variety of applications including heritage preservation (Khairil, et al). High resolution digital cameras are mounted on these vehicles. The overlapping photographs may be processed and converted into scaled photographs (Ortho Photos) using suitable computer programmes based on the photogrammetric principles. The result is a 3D data set of the area including man-made features such as the heritage site and buildings. This may be presented as a footprint for the site or as a Digital Terrain Model (DTM) plus a Digital Surface Model (DSM) of the site showing the various details for the heritage site. Depending on the scale of detail and the information required for the heritage site this may be cost effective way of heritage documentation.

2.1 *Terrestrial Photogrammetry*

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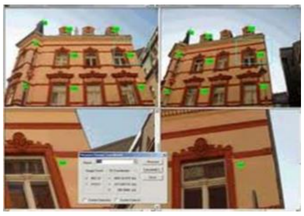
The traditional techniques of using ground based photography for measuring architectural details of a building, involved using terrestrial metric cameras and taking overlapping photographs for the object from priorly established control points. The photographs are then processed using the photogrammetric principles and stereoplotters. Recent advances in digital cameras and technology led to a revolution in terrestrial photogrammetry. Both metric and non-metric high resolution digital cameras are now beginning to be used in heritage documentation and building preservation. Both manual and automatic methods of measurements of data can be made depending on the scale, complexity of the object and the density of data required for the application.



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2.2 *Digital Photogrammetry*

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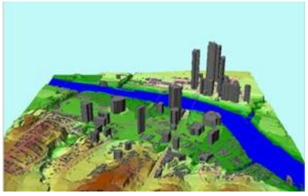

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More recently, with the availability of high definition digital both metric and non-metric cameras, digital photogrammetry is becoming an important source of the 3D data and virtual reality (Alshawabkeh et al, 2002) of the photographed scene. The direct acquisition of digital images has a number of advantages in photogrammetric applications such as direct data flow and quality control, high potential for automation, and good geometric characteristic. The high-resolution digital cameras used in digital photogrammetry applications, provide better image quality with high resolution images based on the Charge Coupled Devices Sensor (CCD) replacing the film known as the digital interchangeable Single Lens Reflex camera (SLR).

The methods used in digital photogrammetric software systems vary according to the specific needs or characteristics of the cultural heritage object, based on digital image rectification, monoscopic multi-image evaluation, stereo digital photogrammetry, and ortho-images.

3 LASER SCANNING

The data for heritage application and documentation may be presented in a variety of ways such as 2D/3D data, plans, elevations, sections, aerial or terrestrial photographs and digital images. However with the availability of IT technology, both software and hardware, the need for presenting data as 3D digital information is increasing hyperbolically. With advances in technology, a wide variety of techniques in addition to traditional surveying are available for heritage documentation and preservation.

The figure below summarises these techniques in terms of scale and object compared to air borne or even satellite, techniques. Laser scanning, from the air or from the ground, is one of those technical developments that enable a large quantity of three-dimensional measurements to be collected in a short space of time (3D Project, English Heritage,2011). This document presents advice and guidance on the of various survey technologies available to heritage and built environment professionals, so that they can choose the most suitable techniques and technology within their budget and time constraints.

The term “laser scanner” applies to a range of instruments that operate on differing principles, in different environments and with different levels of accuracy. A generic definition of a laser scanner, taken from Böheler and Marbs is:

“Any device that collects 3D co-ordinates of a given region of an object’s surface automatically and in a systematic pattern at a high rate (hundreds or thousands of points per second) achieving the results (i.e. three-dimensional co-ordinates) in (near) real time.”

Traditional surveying techniques and technology such as EDM’s (Electromagnetic Distance Measurement) and tapes have been used to survey and digitize a natural surface or a man-made structure such as a building. The limitation of these techniques is twofold: a limited number of points will be measured due to time, and the labour constraints of these techniques. In addition to direct survey techniques, terrestrial photogrammetry has also been used successfully. To alleviate these difficulties 3D laser scanning is becoming a popular method for measuring heritage buildings and the built environment at various stages of design, construction, maintenance and decommissioning.

Three dimensional terrestrial Laser scanning may be defined as the process of producing a Real Time 3D Digital Surface Model (RTDSM) of the structure (object) by subjecting the surface to a low powered laser light generated by a scanner. A typical laser scanner will use lasers, sensors, computer software and hardware. The scanning results are stored in a large set of digital data which is called the “Point Cloud” for various scans. The scans are imported and a registration is created according to the established control points, and the registered point clouds will be unified into one file to form the RTDSM of the scanned structure using the scanners’ relevant software. RTDSM’s may also be converted into digital ortho-photos using software such as Point Tools ***(15)***. The Real Time Digital Surface Model of the structure is represented by 3D space coordinates(X, Y and Z) relative to the instrument station. The relative positional accuracy of the collected data is 5-10mm, depending largely on the scanned surface distance from the scanner and the reflective nature of the surface together with lighting conditions. The data also contains the passive colour (primary) of the material, as different surfaces reflect different laser light intensity. This yields to a number of applications in addition to building surveys and building conservation.

3.1 *How it works*

Essentially there are two types of laser scanners used in heritage building preservation applications, either time of flight (TOF) or phase difference. In both cases a laser light generated by the scanner is directed towards the object. The bounced back pulse is captured by the digital camera imbedded in the scanner. Hundreds of thousands of points are measured per second and a huge surface data file is created which is called the “Point Cloud”. This can be converted into a Real Time Digital Surface Model of the structure (RTDSM) through data registration. The process of scanning will continue until the whole of the structure both internally and externally is covered. In this process the complete RTDSM of the structure is produced by matching the sequential individual scans through the overlapping areas and control stations. The software provided by the scanners enables the processing of this data by eliminating the redundant data and converting the model to any desirable grid. Most modern scanners also capture reflected light intensity in terms of the RGB values (Red, Green and Blue). This is particularly useful in object identification and quality of material determination.

3.2 *Laser Scanning Systems for the Heritage Buildings and Built Environment Projects*

FARO Focus320D
Range of up to 320m
Up to 970,000 points per second
3D Position Accuracy: 2-4mm at 25m
Precision: 2.2mm standard deviation at 25m
Weight 5Kg,Compact Size

Leica Scan Station P20
3D Position Accuracy: 3 mm at 50 m; 6 mm at 100 m
Target acquisition: 2 mm standard deviation up to 50m
Scan rate: Up to 1 million points per second
Weight: 11.9 Kg(w/o batteries) Relatively Large Size

RIEGL VZ-6000
Range of up to 6000m
Up to 220,000 points per second
3D Position Accuracy: 15mm at 150m
Precision: 10mm standard deviation at 150m
Extensive options; measurement and connectivity

3.3 *Retrofitting Heritage Buildings*

The ever increasing demand and the cost of hydrocarbon energy for both domestic and commercial use necessitate updating the heritage buildings by refurbishment, using sympathetic material and technology. In the UK the built environment emissions account for 44% of the total, with only 18% non-domestic buildings, and around 2% newer than 5 years housing stock (Craven, 2011). On the European scale it not difficult to envisage the amount of energy that could be saved by efficiently retrofitting these properties with new energy standards. Large amounts of energy could be saved by using the most energy efficient materials/technology in refurbishment 'retro-fit', combined with the use of sustainable energy produced by green technology such as solar panels, wind, thermal and other sources.

Although laser scanning technology is relatively new in the built environment it is the most useful modern technology for the retro-fit of historical building and other heritage structures. The buildings can be efficiently and accurately scanned, both externally and internally, capturing every detail of the building, including all services, and producing RTDSM's. These scans offer great benefits at various stages of planning, design and construction. Terrestrial laser scanning can also be used in combination with other surveying technology such as airborne data and Terrestrial Digital Photogrammetry. A good example of retro-fit laser scanning applications is the CCEM (Competence Centre Energy and Mobility) project in Switzerland started in 2006 and completed in 2011. A number of Swiss universities together with 20 scientific and industrial partners were involved in the energy efficient retrofit of a housing blocks project.

3.4 *Building Information*

To measure building facades /elevations/plans traditional survey techniques such as the use of total station and terrestrial photogrammetry have been used, however, this is a laborious and time consuming and expensive process, which may require a number of revisits to the site. In addition, only the measured points (limited) can be used to represent the building. Laser scanning technology overcomes most of the above mentioned difficulties for traditional surveying and offers an efficient, accurate and remote measuring system.

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An RTDSM for a building obtained from point clouds can be used for the production of all traditional 2D drawings such as building facades, elevations, and cross sections in any direction through the building. These can then be converted into CAD drawings using AUTOCAD or other software effectively and efficiently. In addition RTDSM's may be used to calculate internal and external areas, volumes, room dimensions, tolerances of finishes and the identification of materials of building elements.

Laser technology also provides effective solutions in the fields of building conservation and digital documentation. It can be used in the survey, extraction and renovation of historic buildings and landmarks in addition to archaeological studies. This technology has been extensively used by both English and Scottish heritage in the UK for both digital documentation and building conservation.

3.5 *Laser Scanning Limitations*

Laser scanning like any other surveying technology has limitations. The scanning process yields large amounts of digital data as point cloud. The post processing of this data may a take relatively long time to deliver the final product. This technology is suitable for producing DSM's of the scanned surface and is not capable of penetrating surfaces to deliver subsurface information. Special care should be taken when there is a break in the surface and where there is dense vegetation cover (airborne laser). Instruments' range limitation should also be noted before embarking on scanning. Depending on the scale and constrains of the project the initial cost of this technology is relatively high as compared to digital photogrammetry. In addition, digital cameras provide instantaneous digital images which can be processed into digital data, thus saving time and cost.

4 GLOBAL POSITIONING SYSTEM (GPS)

The heritage site information consists of floor and site plans, elevations, sections, photos and historical data. This data may have been collected at various times using different survey methods, instrumentation and different local grid or national coordinate system.

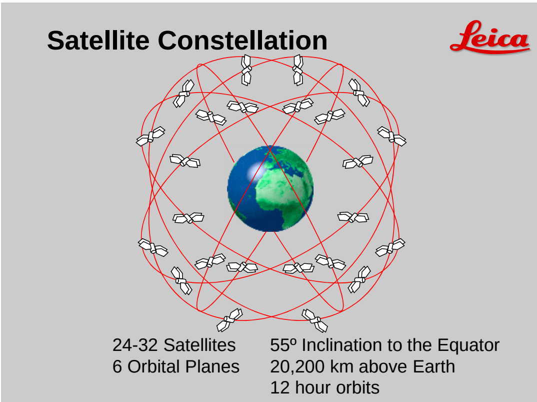
The widely known and used GPS (Global positioning System) is the Global Navigation Satellite System (GNSS). This system was developed by the US Department of Defence. The system uses a constellation of satellites presently orbiting the earth at around 20,200 KM twice a day. These satellites transmit microwave signals which are received by the GPS receivers on earth. This information enables the receivers to calculate their position, satellites' speed, direction and time. A minimum of four satellites are required. The operation of GPS satellites and their positions are determined by US ground control stations. GPS enables the heritage professional to place all this data under the national grid (Ordinance Survey for the UK) or the world coordinates system (WGS84). This unified system would give the heritage and the built environment professional better understanding of the condition and the historical value of heritage sites and their preservation. For heritage building maintenance and preservation, the GPS combined with other survey technology is the most efficient system for the establishment of control and detail site measurements. Data collected for heritage project can be stored and managed efficiently through the Geographical Information System (GIS).

4.1 *Global Navigation Satellite Systems (GNSS)*

In addition to the GPS (U.S.) there are other satellite constellations that also provide free 24 hour signals. The Russians have developed, at same time as GPS, a similar system. Although for political and economic reasons the Russian constellation did not have a constellation for full coverage of the earth. However, the Russian Government showed a full commitment to completing the GLONNASS system of satellites (English Heritage, 2009). Most modern GPS receivers can receive and process both systems. In addition, Europe is also testing its own navigation system called GALILEO. This is a civilian controlled constellation of satellite system compared to the GPS or GLONASS defence systems. An Indian system (Indian Regional Navigation Satellite System) and Chinese Compass Navigation System are also planned.

4.2 *How it works*

For the GPS receiver to find its location on earth, it requires signals from at least four satellites: three satellites for geometric from solution and the fourth for time determination. The basis of GPS positioning is 'triangulation' from satellites .Using distances measured to the satellites, the receiver then uses the geometry of triangles to find its exact position on earth relative to the known satellites' positions. To find the distances, the receiver measures the precise travel time from each satellite and multiplies it by the speed of signal (radio wave/speed of light). There is a precise atomic clock on board of the GPS satellite but not so in the receiver for economic reasons. The fourth satellite signal is used by the receiver to synchronise its time with the satellite clock which eliminates the need for expensive clock in receivers. The modern receivers are capable of predicting and eliminating most of the errors in GPS measurements. The signals sent from the satellites first have to pass through the charged atmospheric particles of the ionosphere and the troposphere. The error created by this is minimized by the signal comparison by the receiver. The other error which the user should be aware of is the so called ‘Multipath Error’. This is when the receiver gets GPS signals reflected from the surrounding’s instead of direct waves from the satellites.



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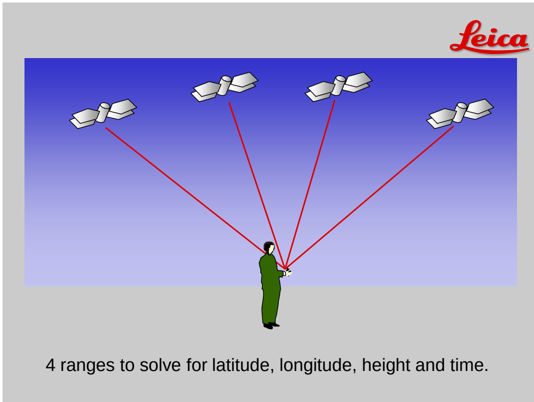

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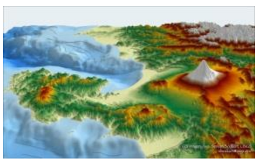
5 GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

As the information for heritage projects may consist of both metric and non-metric data such as maps, plans, sections, photographs, site information and the historical data, the Geographical Information Systems(GIS) is a technology medium for organising and managing this data. GIS is an IT system which allows the entry, storage, analysis, interrogation and visualisation of the digital data. The system stores and manages metric and non-metric data sets in layers interlinked to spatial geo-referenced location through the GIS database. This is a multi-directional editable system that allows the creation of specific application GIS. The system relates the various data through a geographical location index in a similar fashion to that of relational data bases which use a common index to relate different data sets. For example in the case of heritage buildings the geographic data stored as X Y and Z coordinates may contain other data such as date, time, address of the building, construction materials, building methods, structural conditions, historical importance, etcetera. This is a very useful facility for archaeologists, conservationists, architects, engineers and other heritage professionals. Heritage GIS (HerGIS) can be interrogated for specified information. The heritage professional may then analyse, interpret the data and make the appropriate informed decision. There are a number of GIS commercial desktop systems on the market such as ArcGIS, MapInfo, Intergraph, Smallworld etcetera, but the most useful may be those that are available as open source and offer free online access: GIS systems GRASS GIS, MapWindow GIS, Capware, etc.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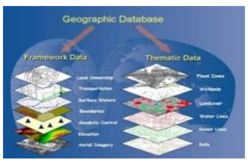

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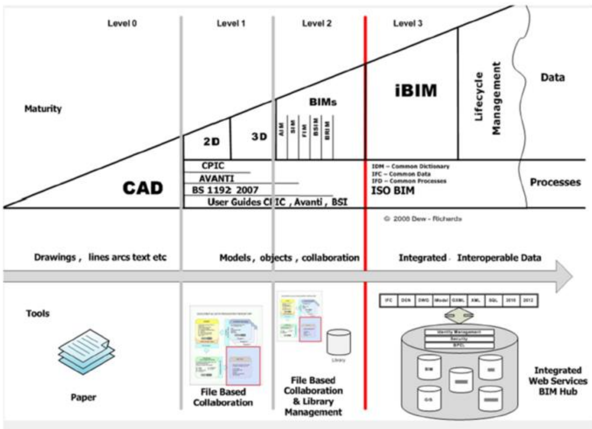
6 BUILDING INFORMATION MODELLING (BIM)

Building Information Modelling (BIM) may be defined as the process of creating and managing building data from the conceptual design stages through to demolition. BIM is a digital three-dimensional, real-time, dynamic building management system in which you can increase productivity and improve quality throughout building design, construction, use, maintenance, demolition or preservation as heritage building. The system inter-connects the spatial building data to all construction materials, processes, use and maintenance throughout its functional life to demolition, which can be shared by all parties.

The UK Government construction strategy was published by the Cabinet Office (May 2011); a report announced the intention to require collaborative 3D BIM (with all project and asset information, documentation and data being electronic) on its projects by 2016. The Government/Industry BIM programme commenced in July 2011 a four year programme for sector modernisation with the key objective of reducing capital cost and the carbon burden from the construction and operation of the built environment by 20%.This depended on a simple assumption that there would be a considerable saving in cost, time, value and carbon emission by making project data available as open source sharable data between various stake holders. Collaborative approach is at the heart of BIM. This will encourage the adoption of most efficient techniques, technologies and processes and share best practices. The BIM task group is helping to spread the objectives of the Government's Construction Strategy to support and strengthen public sectors institutions and all central government departments in the adoption and implementation of a collaborative BIM level 2 by year 2016(BIM, Task Group,2013).



BIM maturity diagram (BIM Task Force 2013)

6.1 *BIM Protocols*

The BIM protocols were produced by the UK Construction Industry Council (CIC) following the UK government's BIM construction strategy report. This has been drafted to support all forms of construction contracts in using BIM to level 2.The protocol also identifies all members of the project teams and the building information produced by various teams. It also sets certain obligations, liabilities and limitations on the use of building information models. The protocol allows the clients to require of particular ways of working. The protocol adopts the main CIC principles in the production of Consultant Appointment and Schedules of Service (CIC/BIM Pro 2013).

6.2 *Heritage BIM (HerBIM)*

Although BIM is designed for new built environment projects with novel (Fei et al,2011) software which allows 3D visualisations with extensive multifaceted parametric data base that facilitates integrative and collaborative approach between the stake holders (Russell, P. and Elger, D, 2008), the 3D digital documentation for heritage buildings consists of various data including manual surveys, nonmetric and metric photography, maps and plans, aerial and terrestrial photogrammetry, ortho-photos and images, laser scanning, topographical, municipal and historical data of cultural importance. BIM is an ideal IT technology that allows the integration of this data into one 3D system. The software also facilitates the archaeological, cultural studies and planning of maintenance and preservation work for the heritage buildings. BIM software also allows the integration of construction materials and methods for heritage buildings. For heritage building preservations this data, combined with geographical locations both inside and outside of the building, gives an efficient tool for the study of the building and design remedies with better understanding of the materials and the construction methods for correct and efficient maintenance of heritage buildings. A good example of HerBIM is the Batawa project (Fei, S. et al, 2011) located northeast of Toronto, Canada which consists of one hundred houses, two unused factories, three commercial buildings and two municipal facilities (Fei et al, 2011) established in 1939.The context of this was the development of 600 hectares of land that includes the town and its rich history. Various parametric and metric data were included in the HerBIM model (including the historical data) and then processed using AutoCAD, Revit, Civil 3D,SketchUp. The model also includes a point cloud generated from Terrestrial Laser Scanning.

7 CONCLUSIONS AND RECOMMENDATIONS

Both digital photogrammetry and Laser Scanning Technology are developing fast into almost every field of applications. This technology is particularly important in heritage documentation, building preservation and built environment applications. The remote laser scanning process produces a huge digital file containing millions of surface points in terms X, Y and Z, in addition to RGB data as a Real Time Digital Surface Model (RTDSM). The RTDSM can be utilized throughout continuous heritage building preservation and full digital documentation. Full details of buildings will help the management, maintenance and preservation of historic heritage sites, in addition to reconstruction in the case of fire or damage. RTDSM can also be used for heritage retrofit projects. This is particularly important in increasing the energy efficiency of older residential and commercial buildings. All infrastructure projects can greatly benefit from this technology. The benefit in terms of the economy and efficiency of RTDSM is particularly significant in heritage preservation. Laser scanning data use can be utilized from the early feasibility studies of a project, to design, construction, operation, maintenance and the decommissioning or preserving of structures for future generations. A RTDSM may be imbedded in BIM or used as a standalone full digital documentation snap shot at the time. The utilization of this technology in archaeological investigations and heritage preservation may not be fully appreciated in the heritage field and generally in the built environment. Indeed this technology has only recently been partially highlighted with the introduction of BIM by the UK Government. This is one of the main reasons for the lack of knowledge and availability of modern surveying technology. One of the aims of this paper is to highlight the suitability, economy, availability and capability of modern surveying technology including laser technology digital photogrammetry to heritage and other built environment professionals. Both laser scanning technology and digital photogrammetry are significantly important sources of digital documentation for heritage buildings' preservation and management, and can add value by reducing the carbon burden in the built environment, particularly in the era of BIM, especially if it is combined with other modern surveying technologies. Both laser scanning and digital photogrammetry are relatively new technologies in the heritage and built environment, and there are many applications in both that can be explored or tested, and compared with other surveying technologies, to ensure current and future heritage preservation.

8 ACKNOWLEDGMENTS

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